Feedback Systems in RHIC

Orbit and Energy Feedback

Tune and Coupling Feedback

measurement
feedback design
history
major changes for realization
examples from run-11

Impact on RHIC Performance
- accelerator availability
- operation under extreme conditions (accelerator reliability)
- "up-and-down" ramps

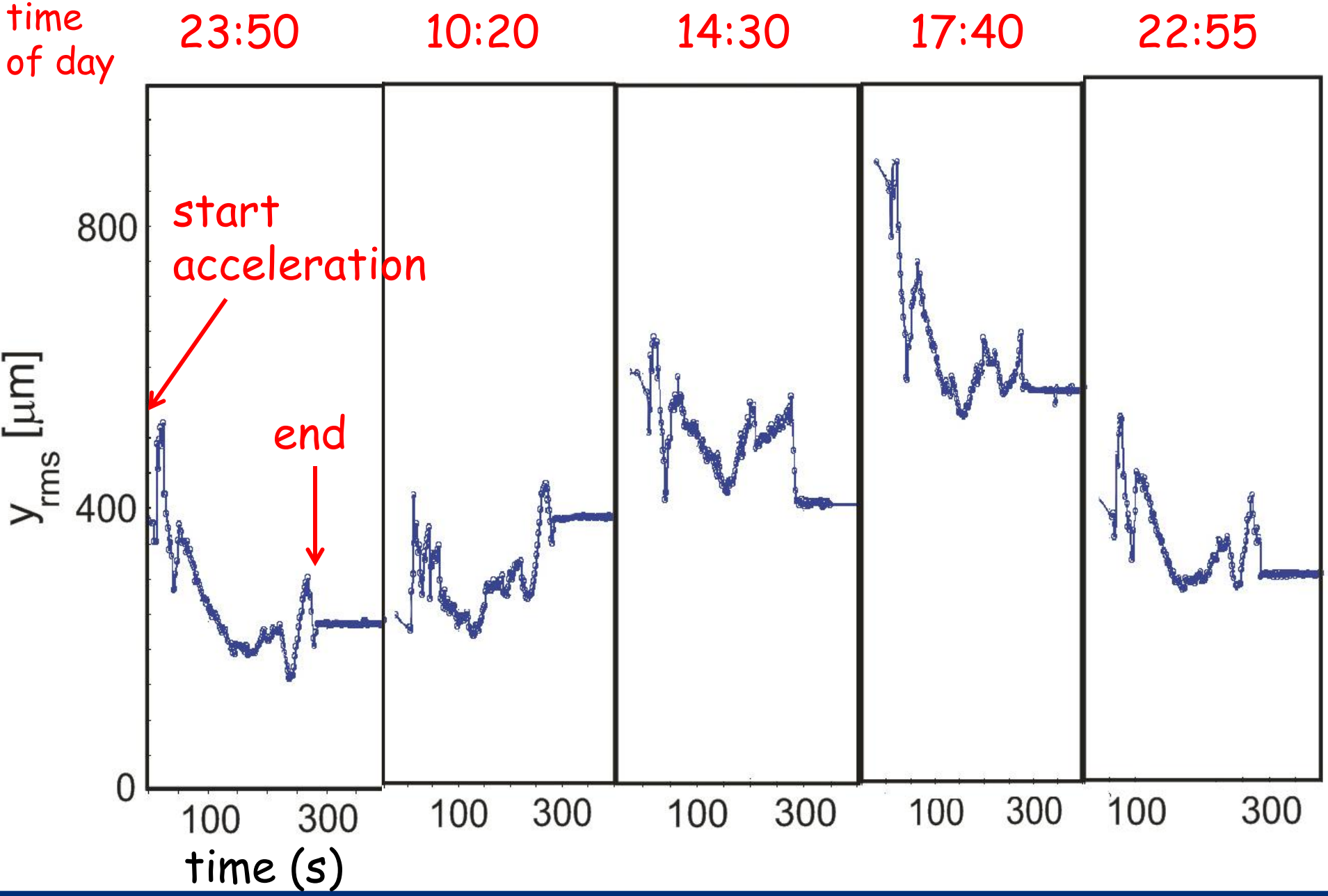
Summary

(Beam Transfer Function Measurements)

Acknowledgements

WHY AT RHIC

y_{rms} during acceleration, run-9



RHIC ORBIT FEEDBACK

measurement

based on existing beam position monitors
using new and improved algorithm for measuring average orbit
using original survey (e.g. offset) data
deterministic data delivery

feedback design

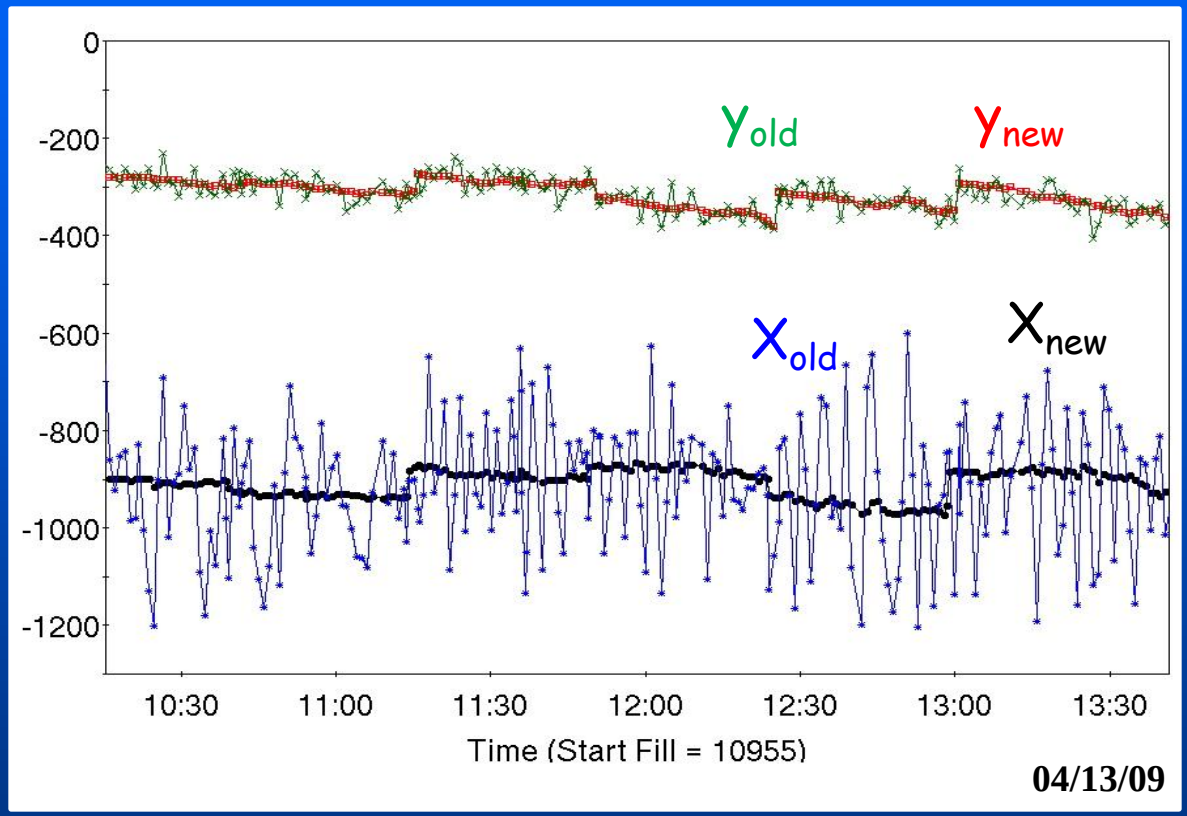
orbit correction algorithm ("singular valued decomposition")
extended to application at 1 Hz rate during energy ramp
reference orbits specified in terms of BPM data (not corrector strengths)

history

proof-of-principle for orbit feedback using existing infrastructure (2010)
energy feedback principle improved (2011)
constrain average horizontal corrector strengths
use all arc BPMs for energy offset determination
implementation of orbit and energy feedback on all ramps (2011)

orbit feedback development: BPM precision

uses digital equivalent of a single-pole, low pass filter (IIR filter) to effectively average out predominantly ~ 10 Hz variations in the closed orbit

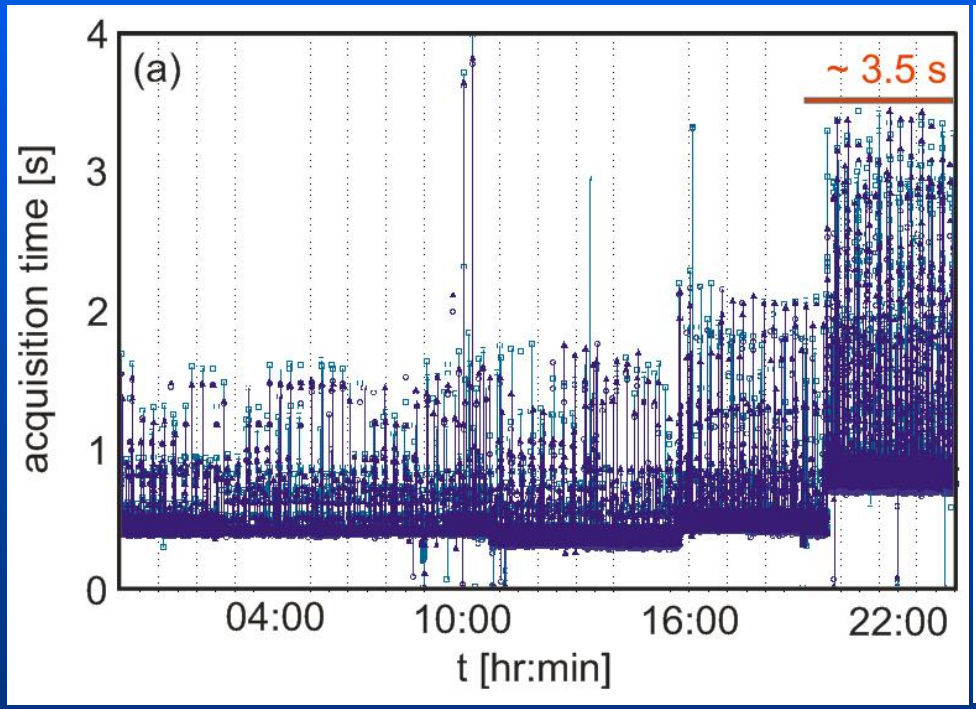


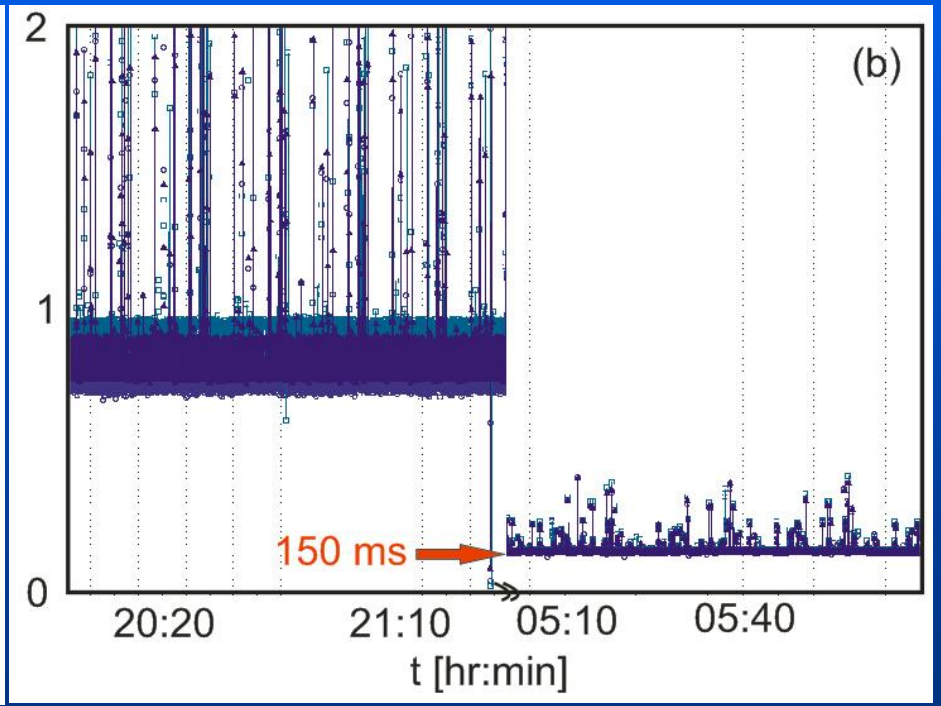
★ precision of average orbit measurements improved by > factor 10

orbit feedback development: BPM data delivery

pre-RUN10
- acquisition rate: nominally 0.5 Hz
- nondeterministic

RUN10
- ★ acquisition rate: 1 Hz
- deterministic

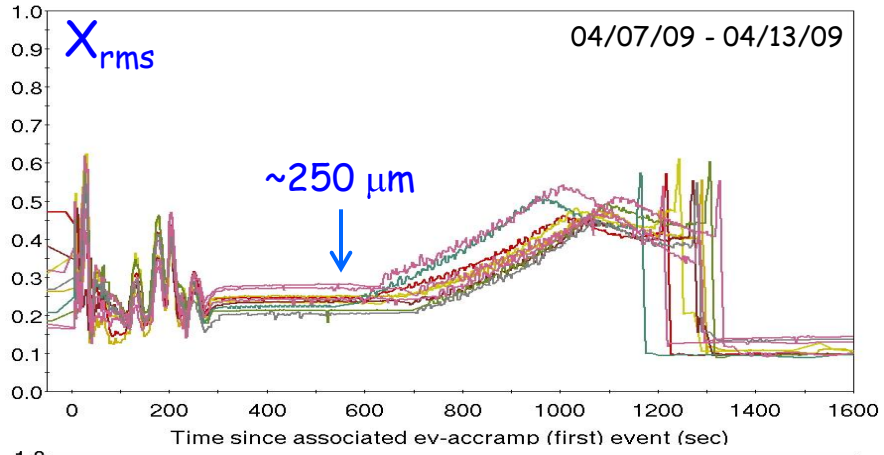


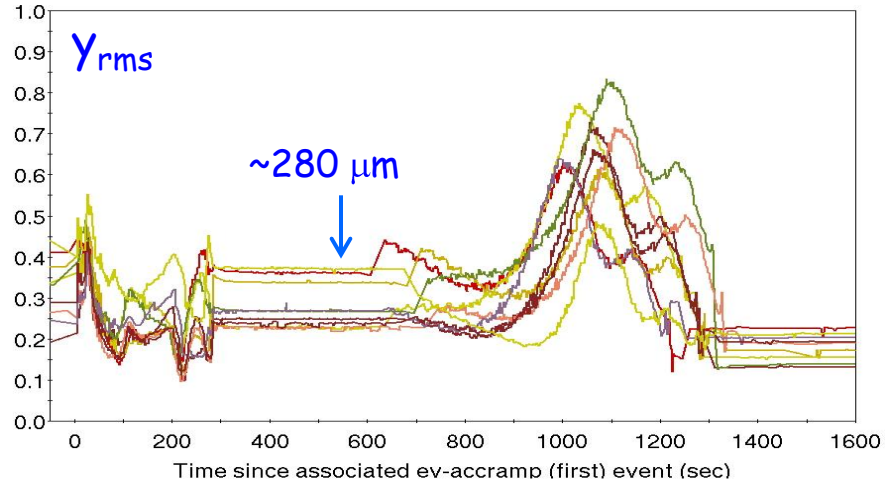


ORBIT FEEDBACK AT RHIC

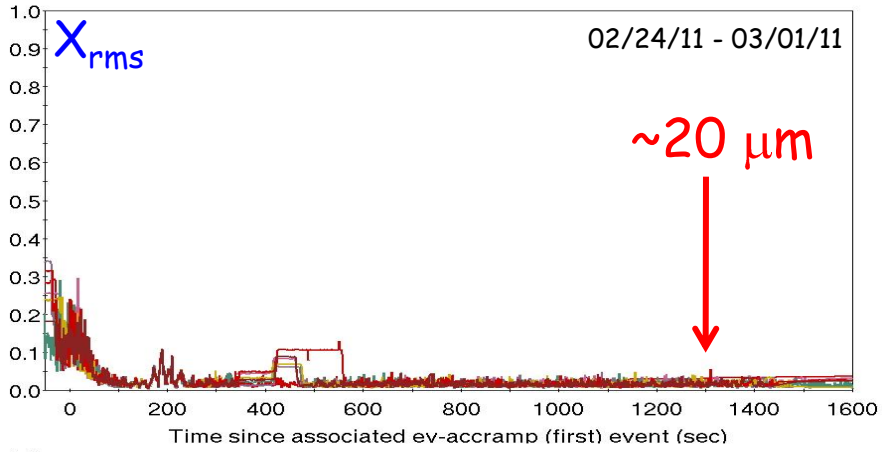
BLUE RING

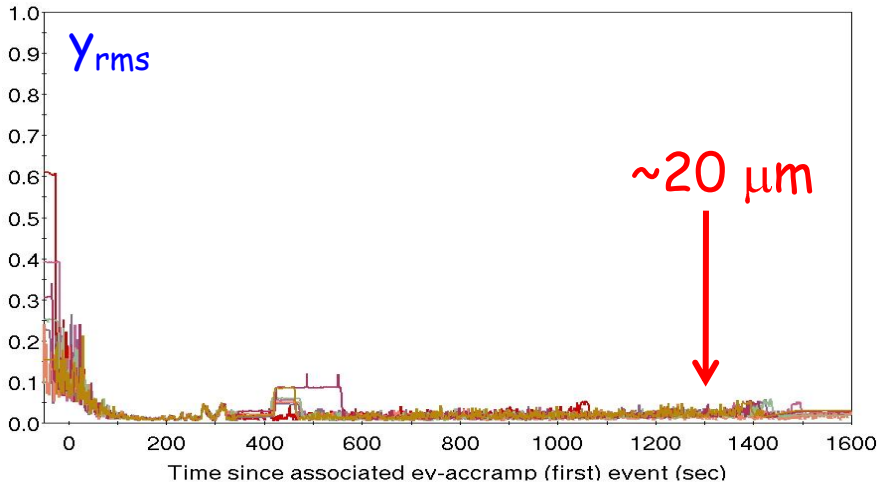
run-09





run-11





★ orbits well controlled, reproducibility is excellent
orbit feedback now essential for polarized proton operations

RHIC TUNE AND COUPLING FEEDBACK

measurement

based on direct-diode detection (BBQ = base-band tune) for precision measurements - M. Gasior , R. Jones (2005)

feedback design

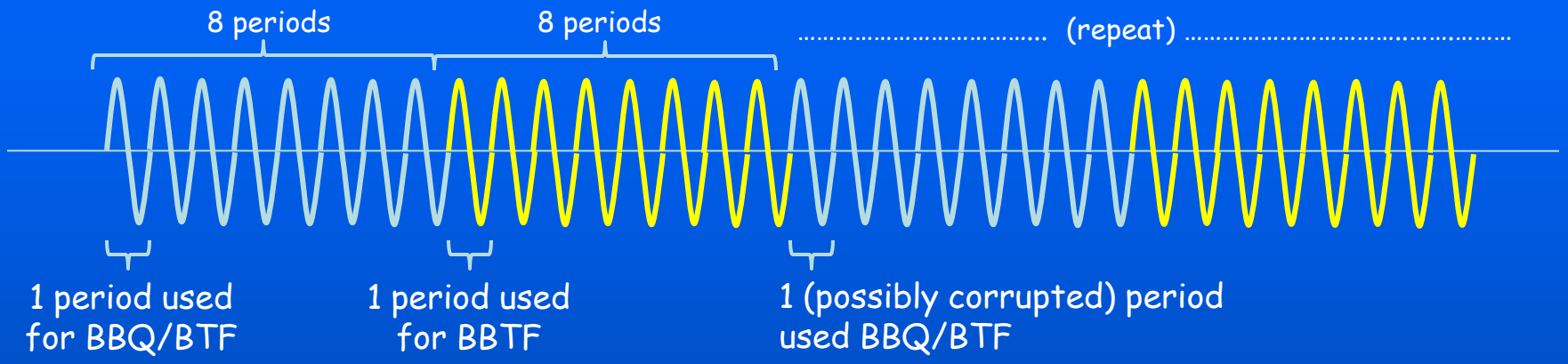
uses methodology of coupling angle measurement – Y. Luo (2004)
distinguishes between eigenmodes - R. Jones, P. Cameron, Y. Luo (2005)

history

demonstrated at RHIC in 2006 - P. Cameron et al (2006)
successfully applied for all ramp developments in 2009
used regularly by operations for ramp development in 2010
used together with orbit and energy feedback for all ramps in 2011

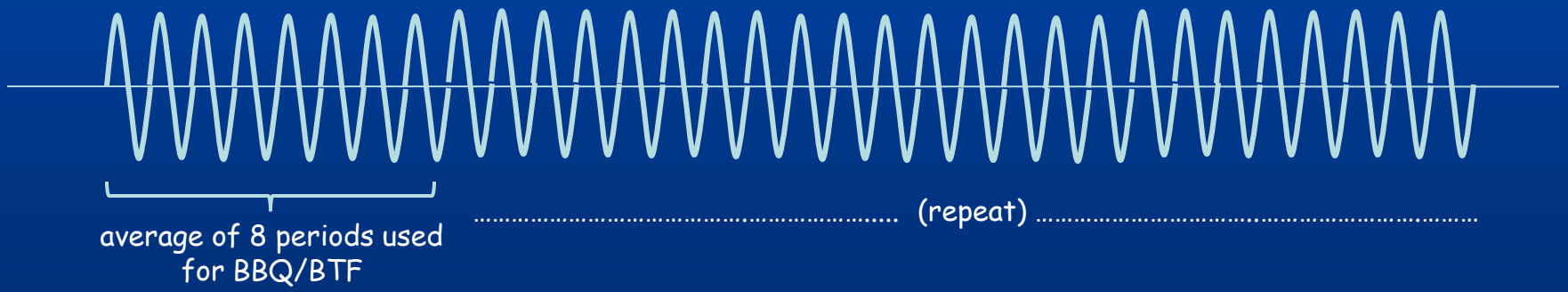
tune/coupling feedback: measurement precision

before:

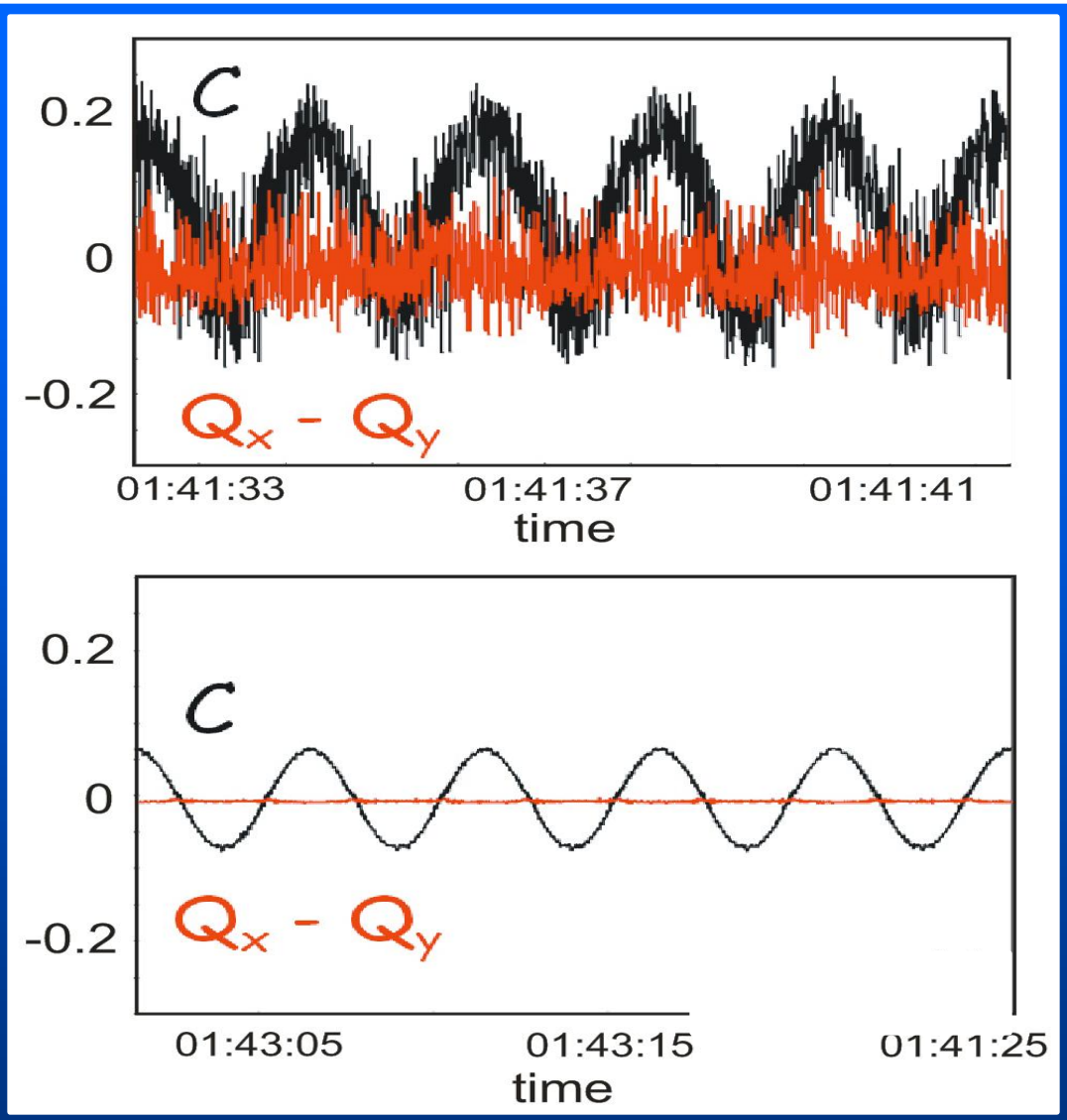


➡ 1 in 16 periods of data (AFE output, I/Q demodulator input) used for BBQ/BTF
intermittent corruption of this data due to CPU-limits and
data overwrites with BBTF (ADOs removed)

after:

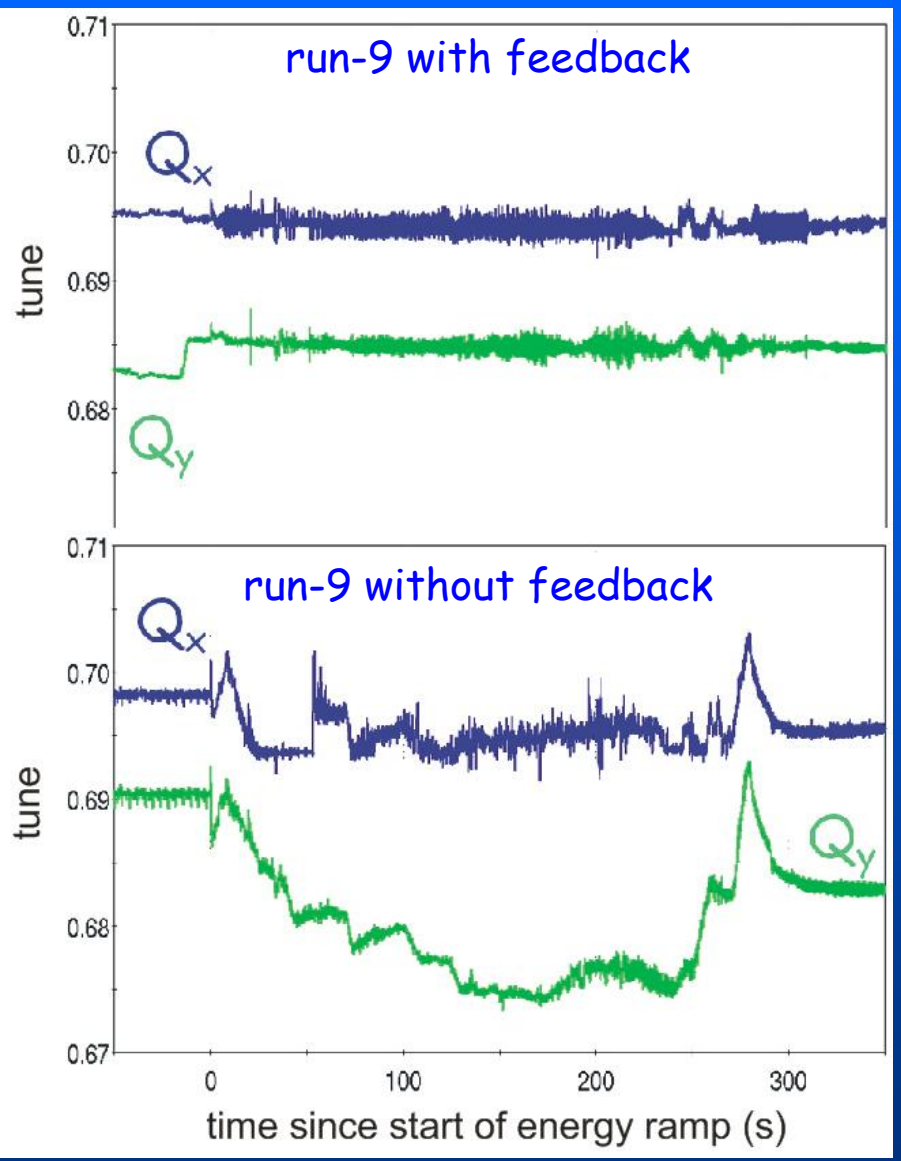


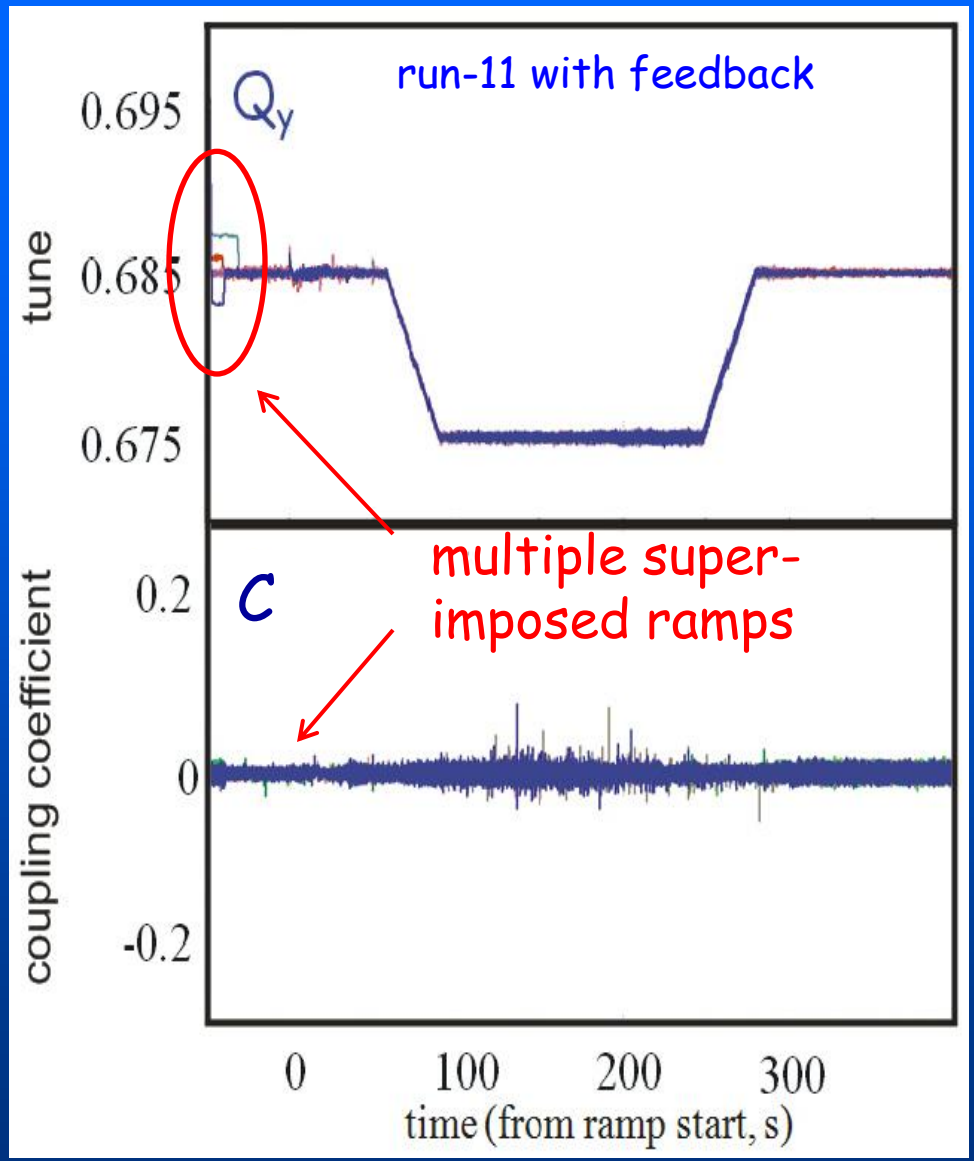
tune/coupling feedback: measurement precision



> factor 10 improvement in measurement resolution

TUNE/COUPLING FEEDBACK AT RHIC





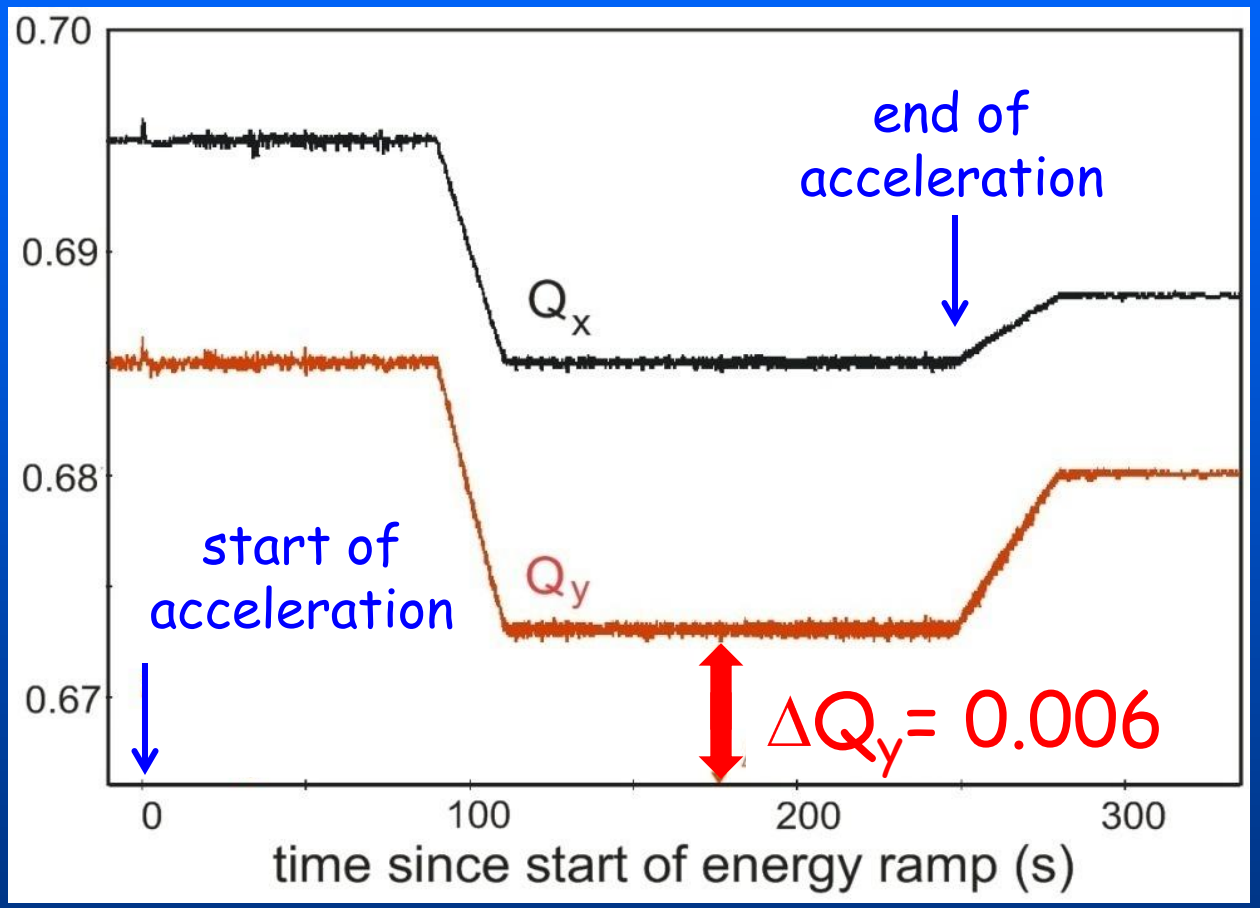
tunes and coupling well controlled, reproducibility is excellent

Impact on RHIC performance
(1) Accelerator availability

year	methods used	time to first successful acceleration
< 2009	iterative orbit and tune/coupling control	~ 3 days
2009	iterative orbit control tune/coupling fb	~ 8 hours
2010	orbit fb development tune/coupling fb	~ 4 hours
2011	orbit and tune/coupling feedback (on all ramps)	~ 2 hours

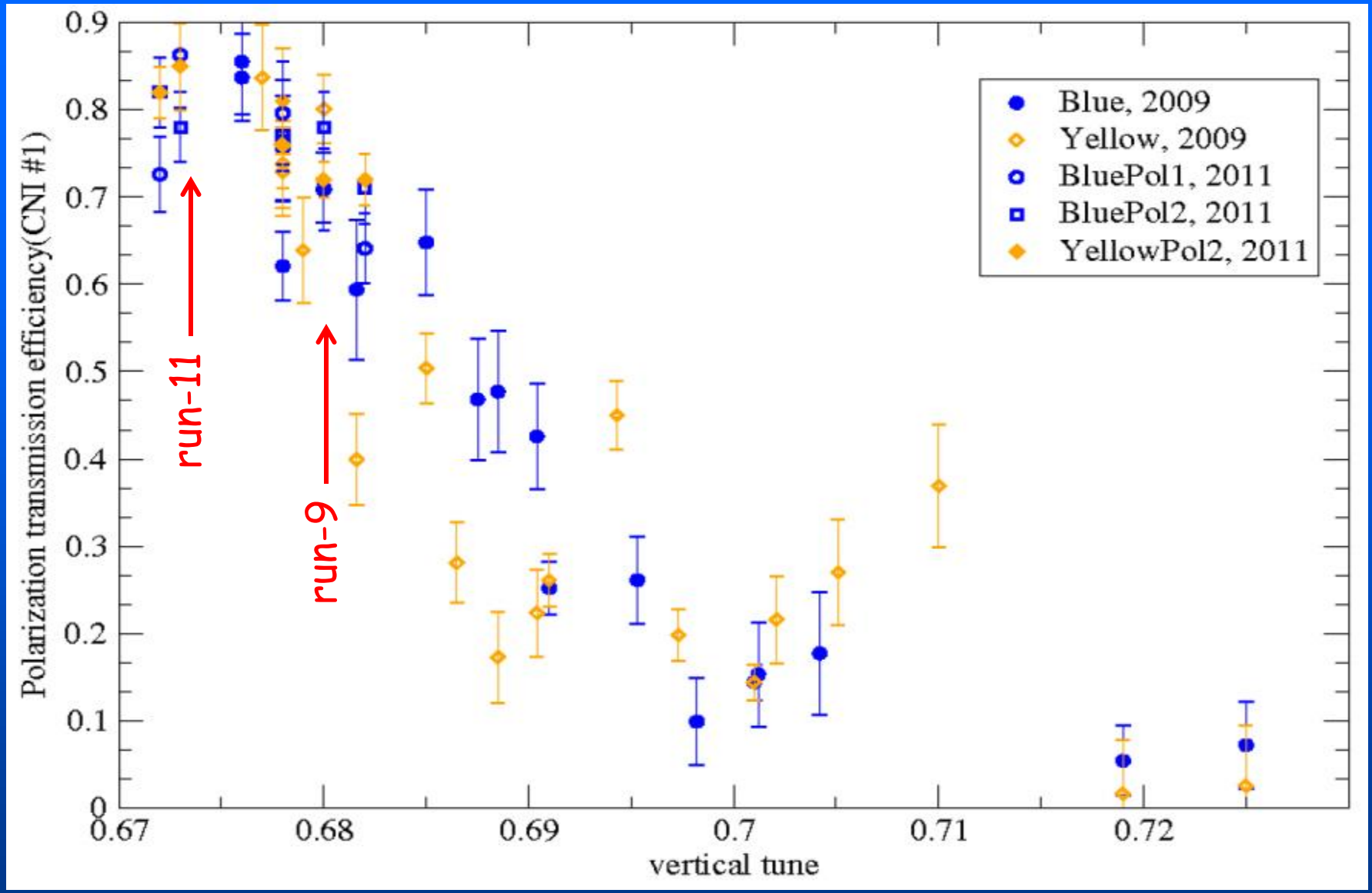
Impact on RHIC performance
(2) operation under extreme conditions: near-resonance acceleration during run-11

7/10 snake resonance



2/3 resonance

With routine orbit, energy, tune, and coupling feedback on every acceleration of protons to high energies, the vertical tune could be lowered towards dangerous 2/3 orbital resonance (and away from spin resonance at 7/10).

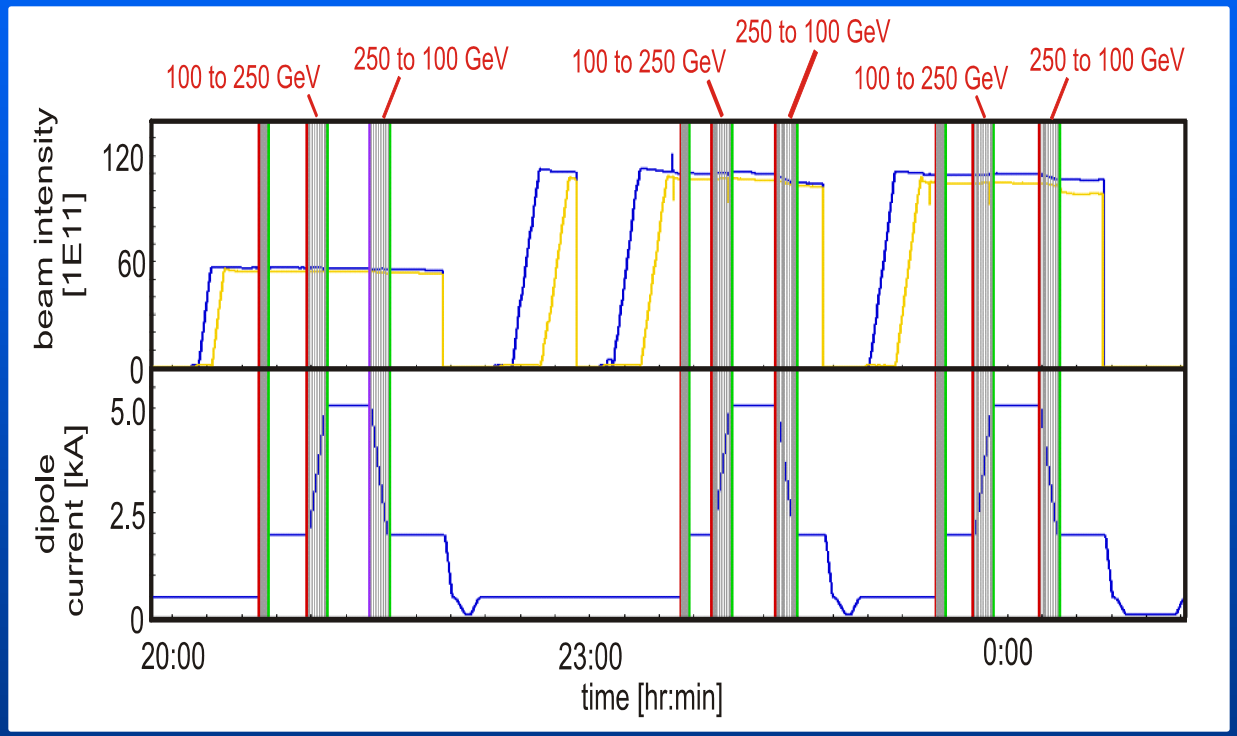


~ 25 % increase in relative polarization of each beam

Impact on RHIC performance
(3) acceleration/deceleration

A dedicated study was performed to measure the polarization asymmetry measured before acceleration and after identical deceleration

New chromaticity feedback + orbit, energy, tune, and coupling feedback



action of feedback:

		100 to 250 GeV	250 to 100 GeV
BLUE	orbit	< 0.04 mrad (x,y)	< 0.04 mrad (x,y)
	tune	< 0.015 (x)	< 0.04 (x)
		< 0.020 (y)	< 0.10 (y)
	coupling	< 0.04 (x,y)	(< 0.7 (x)), < 0.25 (y)
	chromaticity	~ 7 (x,y)	~ 12 (x)
			~ 10 (y)
YELLOW	orbit	< 0.02 mrad (x)	< 0.05 mrad (x)
		< 0.01 mrad (y)	< 0.02 mrad (y)
	tune	< 0.01 (x)	< 0.04 (x)
		< 0.01 (y)	< 0.07(y)
	coupling	< 0.01 (x,y)	< 0.1 (x), < 0.5 (y)
	chromaticity	~ 5 (x,y)	~ 20 (x)
			~ 40 (y)

Feedback essential for realization (huge corrections during deceleration)

First ever demonstration of fully automated beam control (at least in high energy hadron accelerators)

Summary: Measurement Precision

parameter	stability no feedback	stability with feedback	used in normal operations
ORBIT			
X_{rms} y_{rms}	~ 1 mm	~20 μm	YES
TUNE			
Q_x Q_y	~ 0.02	~ 0.001	YES
COUPLING			
|C-|	~ 0.04	~ 0.01	YES
Δ			
ENERGY, X_{mean}	~ 250 μm	~15 μm	YES
CHROMATICITY			
ξ_x ξ_y	~ 10	~ 3	NO

Summary: Feedback Systems in RHIC

improved measurement resolution

↓

improved ability to control beam's properties

+

demonstration of feedback-based beam control

↓

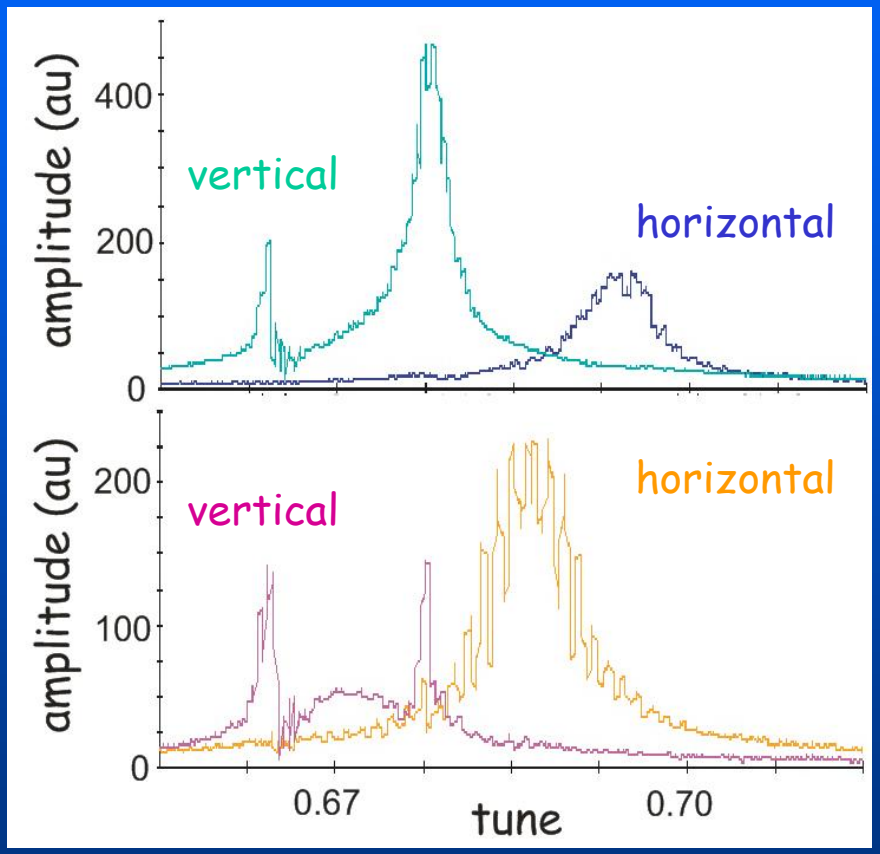
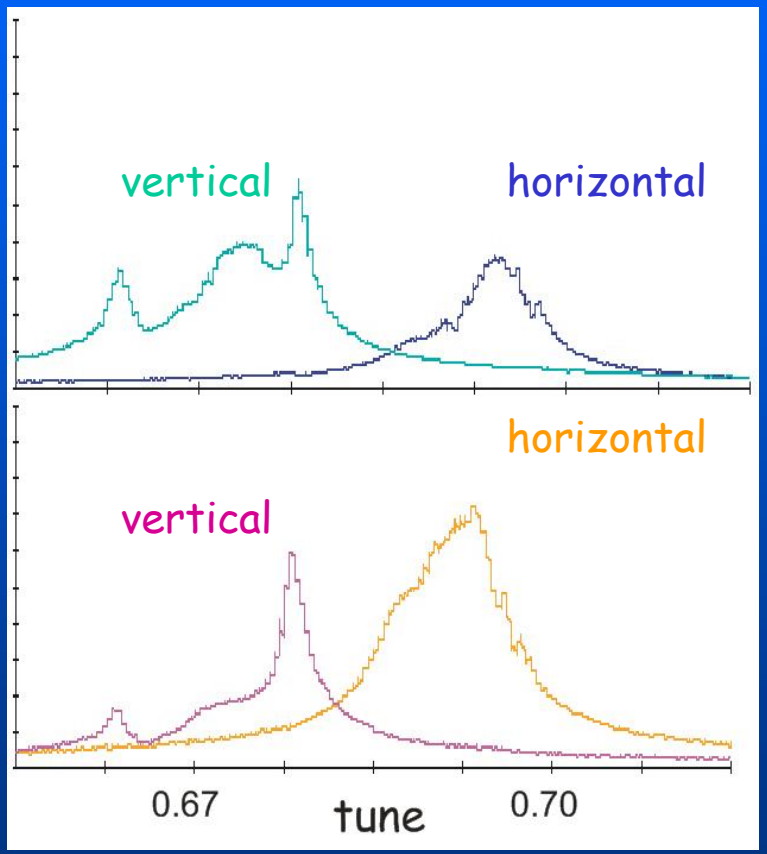
higher accelerator availability (~ 1 week/run)

+

higher polarization, guaranteed reproducibility,
elimination of human error factors,
transition from pre-programmed to feedback-based control

RHIC Beam Transfer Function Measurements

250 GeV, polarized protons

	without 10 Hz feedback	with 10 Hz feedback
blue ring		
yellow ring		

★ intrinsic resolution (versus 10 Hz interferences) of instrumentation now observable

Acknowledgements

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Orbit feedback T. D'Ottavio, A. Marusic, V. Ptitsyn, G. Robert-Demolaize

Tune/coupling feedback

P. Cameron, A. DellaPenna, M. Gasior (CERN), L. Hoff, R. Jones (CERN), Y. Luo, A. Marusic , C. Schultheiss, C.Y. Tan (FNAL), S. Tepikian

A. Curcio, C. Dawson, C. Degen, Y. Luo, G. Marr, B. Martin, A. Marusic, K. Mernick, P. Oddo, T. Russo, V. Schoefer, M. Wilinski

Chromaticity feedback A. Marusic, S. Tepikian

Energy feedback A. Marusic, K. Smith

10 Hz feedback

P. Cerniglia, A. Curcio, L. DeSanto, C. Folz, C. Ho, L. Hoff, R. Hulsart , C. Liu, Y. Luo, W.W. MacKay, G. Mahler, W. Meng, K. Mernick, R. Michnoff , C. Montag, R.H. Olsen, P. Popken, V. Ptitsyn, G. Robert-Demolaize, P. Thieberger and many others

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Operations G. Marr, V. Schoefer , R. Smith, J. Ziegler

Management W. Fischer, T. Roser

Backup / Old slides

reduced operating costs:

~ $ 100k savings for initial beam setup

~ $ 100k supporting operational mode changes (particle species, energies, optics)

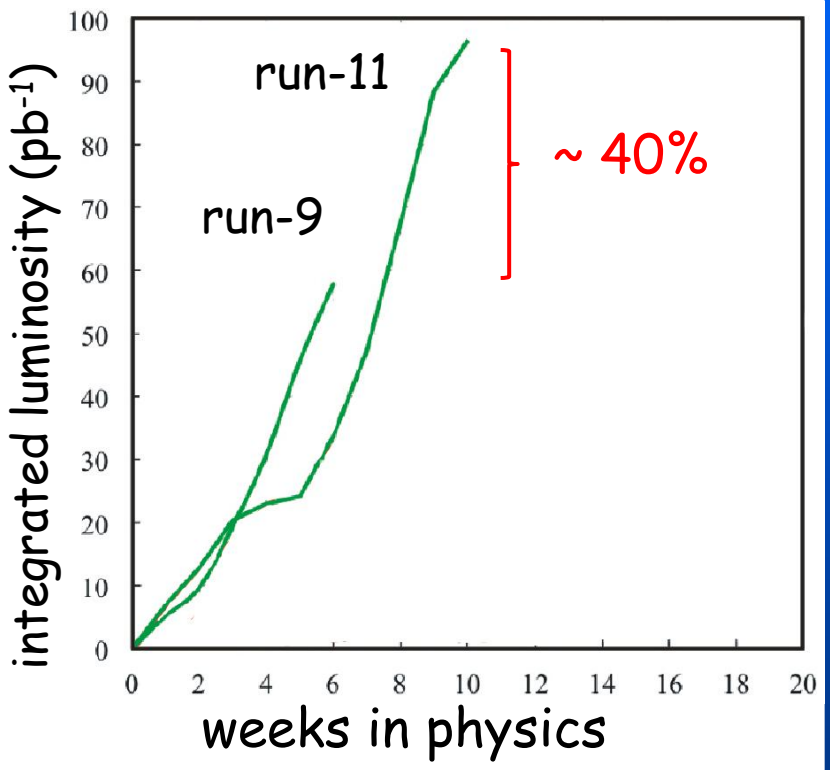
~ $ 100k eliminated need for dedicated re-optimization efforts

> $300k per running period

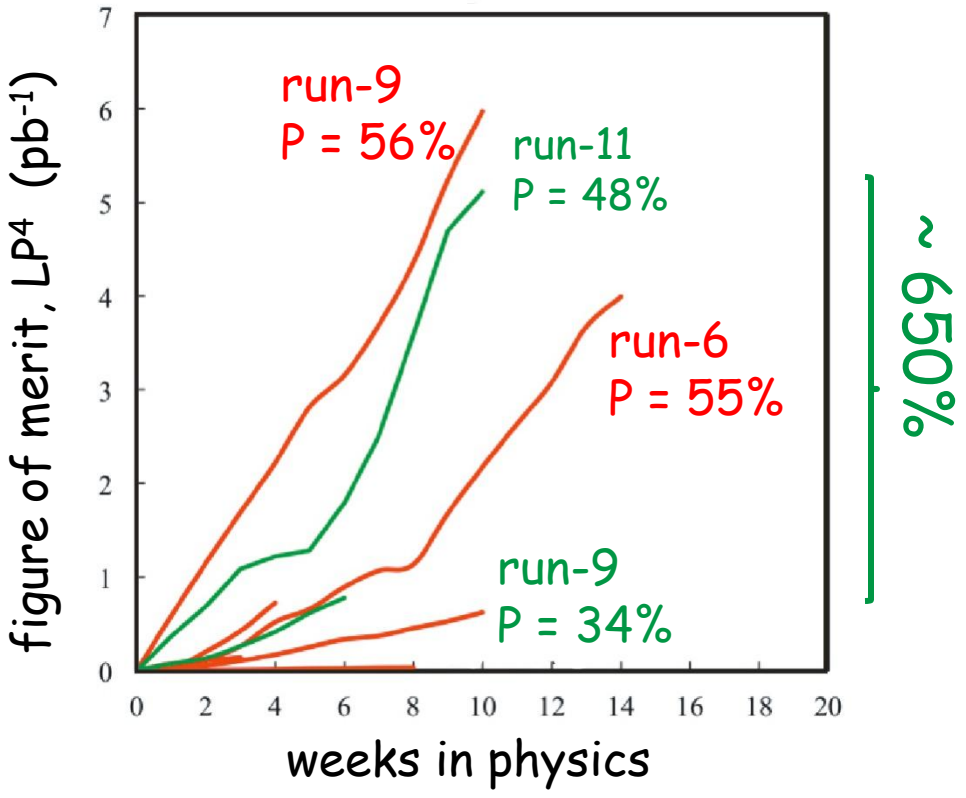
equivalent to > 1 extra week for physics operation

Impact on RHIC performance
(4) RHIC luminosity with polarized protons (250 GeV)

2011: 9 MHz rf system + fb



2011: AGS JQ+ MMPS fix + (9 MHz) + fb

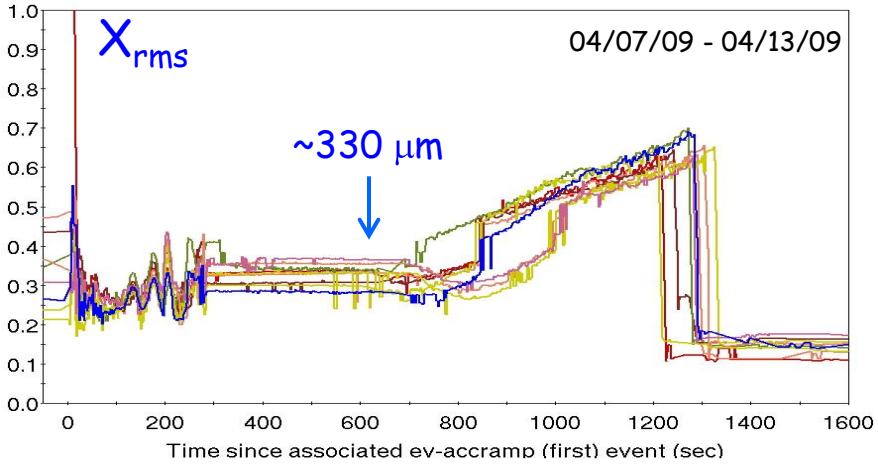


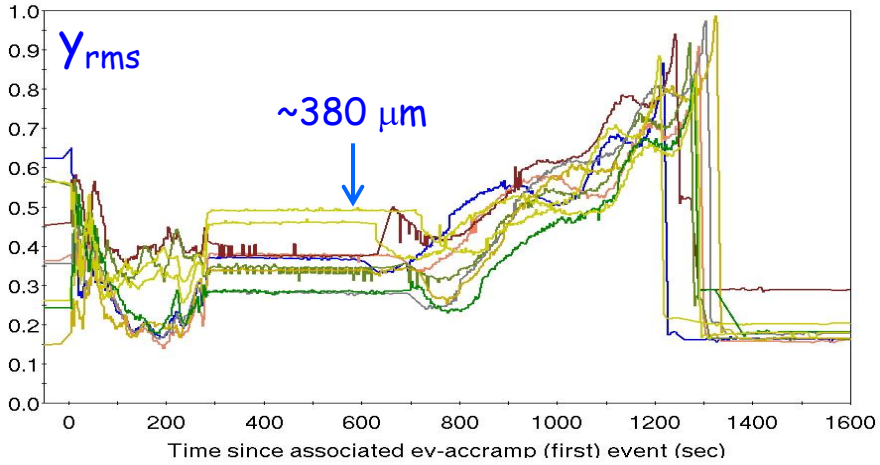
250 GeV
100 GeV

ORBIT FEEDBACK AT RHIC

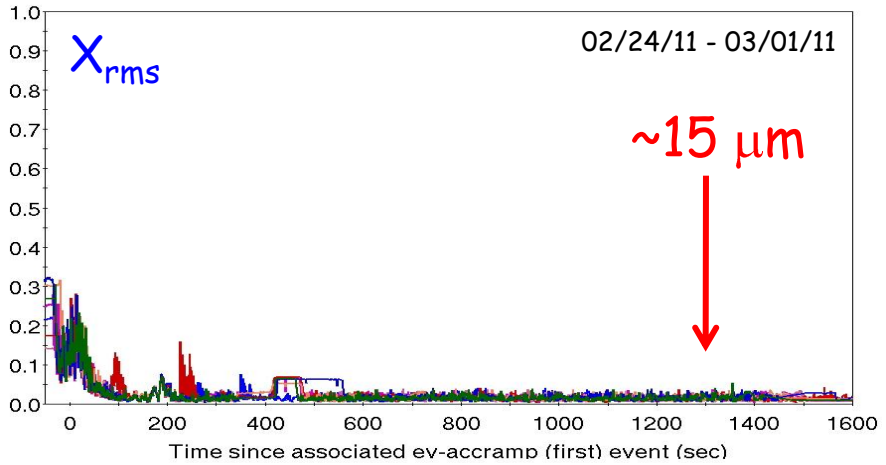
YELLOW RING

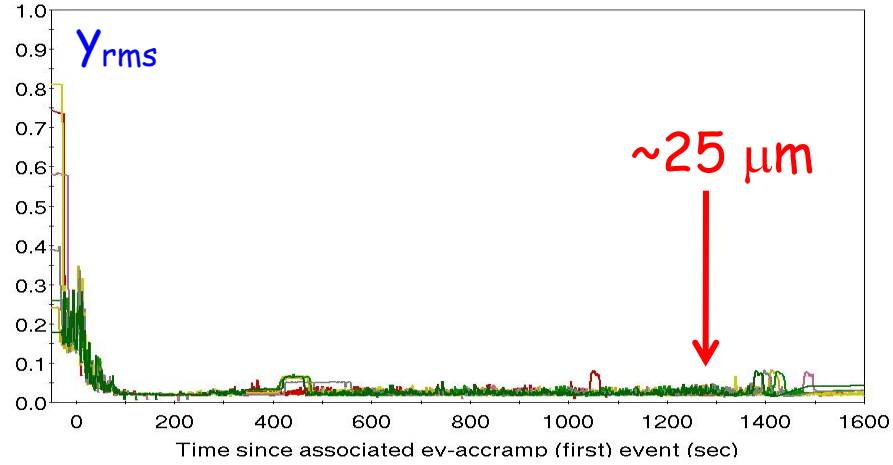
run-09





run-11





★ orbits well controlled, reproducibility is excellent
orbit feedback now essential for polarized proton operations